ATLAS AXIAL RADIOGRAPHY*

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Abstract

The Atlas pulsed-power machine [1] is a 23-megajoule capacitor bank that delivers 28 mega-amperes in a 5 microsecond rise-time pulse into a cylindrical imploding liner, which often contains a target. It is used to study the hydrodynamic behavior of various materials under well-controlled high-energy conditions. X-ray imaging or radiography is used to infer trajectories and velocities of the shockwave and the material interfaces in the target. The axial radiography diagnostic records four high-speed flash x-ray snapshots through the target axis during an experiment. These images provide important benchmarks for various hydrodynamic codes currently used to predict the behavior of shocked materials.

Four Marx-driven x-ray diode sources [2], designed by Los Alamos National Laboratory (LANL) and fabricated by Bechtel Nevada, are used. Each source has a pulse duration of 20 nanoseconds full-width half-maximum (FWHM) that thereby freezes the motion of the target [3]. The x-ray images are converted into blue visible light by a scintillator. Two 8-inch-diameter doublet lenses relay this image 6 meters away into a microchannel plate image-intensified framing camera, contained in a screen box. The machine energy destroys the scintillator and sometimes the first relay doublet. The optical relay is realigned for each experiment. Calibration images are stored for each shot. The image data are sent over fiber-optic cables for remote recording.

I. INTRODUCTION

The Atlas pulsed power machine consists of 24 large capacitor banks in 12 oil tanks that feed energy into a central “load” through tapered arms. This energy magnetically implodes a cylindrical liner onto a target at high speeds to study material properties under shocked conditions. The Atlas axial radiography images are coordinated with other images to give a more complete representation of where, when, how fast, and how the shock waves and material features move through the volume of interest. These images view what happens to the test target in the Atlas machine when viewed along the center machine axis. They are used to refine physics models of shocked materials.

The Atlas axial radiography diagnostic design uses x-ray sources located on the top of the Atlas machine, a scintillator located just under the Atlas load, an optical relay system, and a recording camera box located underneath the Atlas machine. This system records a single frame from each of four x-ray heads on the far side of the load (Fig. 1). This diagnostic has evolved from the axial x-ray system that was used at the LANL Pegasus pulsed power machine and later on Near Term Liner eXperiments (NTXL) at the Shiva Star pulsed power machine.

II. DETAIL

On top of the Atlas machine, four x-ray Marx banks store energy until it is delivered to the x-ray heads. The Marx banks consist of 25 stages of 5.4 nF capacitors [4]. These capacitors are charged to ~34 kV inside a sealed, pressurized (80–100 psi) canister. Each Marx bank delivers more than 20 J to its x-ray head. The four x-ray heads are set up nearly one behind the next, but offset just enough so that the forward heads will not shadow the x-ray output of those behind it. This causes only a slight amount of parallax between the images. The x-ray source spectrum is bremsstrahlung radiation with a maximum endpoint energy of ~300 keV that includes a strong tungsten K-line spike at ~60 keV. They operate with a pulse length of approximately 20 nanoseconds [3]. A single “flash” is approximately 150 mR at 30 cm along

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14. ABSTRACT
The Atlas pulsed-power machine [1] is a 23-megajoule capacitor bank that delivers 28 mega-amperes in a 5 microsecond rise-time pulse into a cylindrical imploding liner, which often contains a target. It is used to study the hydrodynamic behavior of various materials under wellcontrolled high-energy conditions. X-ray imaging or radiography is used to infer trajectories and velocities of the shockwave and the material interfaces in the target. The axial radiography diagnostic records four high-speed flash x-ray snapshots through the target axis during an experiment. These images provide important benchmarks for various hydrodynamic codes currently used to predict the behavior of shocked materials. Four Marx-driven x-ray diode sources [2], designed by Los Alamos National Laboratory (LANL) and fabricated by Bechtel Nevada, are used. Each source has a pulse duration of 20 nanoseconds full-width half-maximum (FWHM) that thereby freezes the motion of the target [3]. The x-ray images are converted into blue visible light by a scintillator. Two 8-inch-diameter doublet lenses relay this image 6 meters away into a microchannel plate imageintensified framing camera, contained in a screen box. The machine energy destroys the scintillator and sometimes the first relay doublet. The optical relay is realigned for each experiment. Calibration images are stored for each shot. The image data are sent over fiberoptic cables for remote recording.

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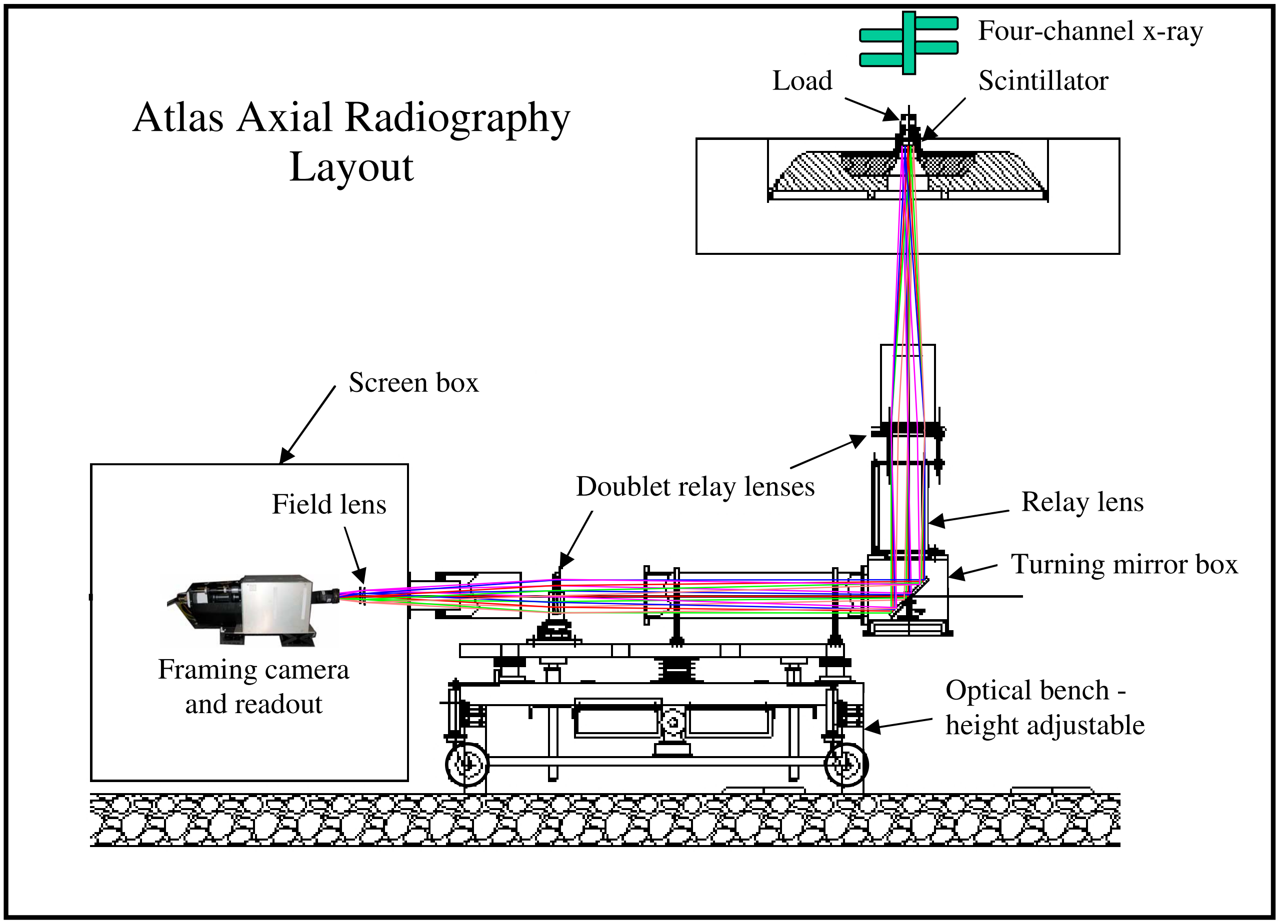

Figure 1. Atlas axial radiography layout

the beam path [5]. The x rays pass through a vacuum window, the target volume being tested, and onto a scintillator. The scintillator converts the x-ray shadowgram into blue light that is optically relayed away from the destructive region to a camera system.

In the past, we used a 2.6-inch-diameter by 1-mm-thick thallium-doped sodium iodide (NaI:TI) scintillator crystal because of its high light output and fast response. Light is emitted in all directions. A reflective aluminum coating is put on the back side of the scintillator to increase light output in the forward direction. The scintillator thickness was chosen as a compromise between x-ray absorption and imaging resolution. The NaI scintillator light output peaks at about 410 nanometers, with full-width half-max points at about 360 and 470 nanometers. It has a quick rise time and a nearly exponential fall time. The 1/e light decay time is 250 nanoseconds [6], so each x-ray image has to be separated by more than 750 ns from the next. An optical fiber is used to collect some of the light into a photomultiplier tube for a time history of the light emission from the scintillator made by the four x-ray pulses. [Note: For future experiments we plan to use crystals of lutetium oxyorthosilicate (LSO) doped with cerium, cut and polished flat to a 1-mm thickness. The LSO has fewer image blemishes, and the 1/e light decay time is much shorter.]

The blue scintillator light is optically relayed to a recording camera system. The optical relay consists of two 8-inch-diameter doublets, a field lens, and a camera lens. The doublets have a focal length of about 1380 mm. A 200 mm x 300 mm x 20 mm plane aluminized rectangular turning mirror between the doublets directs the light horizontally toward the camera box. The mirror is flat to within six waves over the mirror. It is mounted with an aluminum backing plate for support at 45 degrees from the vertical. A mirror enclosure, large piping, and black cloth keep stray light from reaching the camera. The large doublets relay the scintillator picture at unit magnification to an intermediate image over a distance of 19 feet. Positioned just before the intermediate image, a 160-mm focal length, 80-mm-diameter field lens directs the light into a camera lens. The camera lens is a 50mm f/2 macro lens. We searched for the fastest off-the-shelf lens available that could focus well at close conjugates. This lens focuses the light onto a microchannel plate (MCP) image intensifier.

The relay system operates at a 0.37 reduction ratio. The relay system focuses light at f/2.7 and has a 50% MTF of 13 lp/mm at the camera or 4.8 lp/mm at the scintillator over its larger format. Laboratory measurements through the optical system confirm that the optics have better resolution than the camera. The optics are aligned using

low-power alignment lasers and cross-hair reticles. Lens, mirror, and camera mounts allow X, Y, Z, and tilt adjustments.

The camera system consists of the MCP, a framing camera, and a readout camera. The MCP amplifies the image signal and gates out background light that may come before or after the desired images. The MCP is charge-limited so that if all of its charge is depleted in a given image area, its light will not cause the framing camera to go into saturation. We typically integrate the light on the MCP for three to five times the scintillator 1/e light decay time for each sequential image to collect as much light as possible.

The output of the MCP goes through a fiber-optic coupler and onto a blue sensitive Rohrer II framing camera. The framing camera output is four images in a 2 x 2 matrix to make a nearly 2-inch-square composite image. This image is coupled through a 75-mm-diameter to 37.5-mm-diameter fiber-optic reducer (2:1 reduction).

The image from the reducer is read out by a 1-inch-by-1-inch charge coupled device (CCD) image chip. This readout camera is a 2048-by-2048 pixel CCD cooled internally by Peltier solid-state coolers. Air is pumped out of the camera down to near one torr pressure. The camera hot plane is cooled by a water-filled chiller. Digital delay signal generators send gate triggers to the camera system. The 16-bit deep images are transmitted from the readout camera to a computer through fiber-optic signal lines.

The camera system is located inside an electromagnetic interference (EMI) shielded enclosure called a screen box. All screen box equipment is powered through uninterruptible power supply (UPS) units enclosed inside. The screen box has an integrated air-conditioning unit to cool the enclosed equipment.

After the optical relay system has been set up, the scintillator can be replaced with a resolution pattern illuminated by a blue light source. Placement and removal of the scintillator or calibration patterns are accomplished by using a long PVC pipe to reach up under the Atlas target area. Optical mages of a dot pattern are also recorded as a distortion measurement. The scintillator is then re-inserted to take static x-ray calibration images.

Energetic experiments destroy the scintillator and sometimes the first optical doublet lens. These components are replaced when damaged. The optical system alignment is re-established and new calibration images are taken after each experiment.

III. RESULTS

We have taken axial x-ray images on several Atlas events at LANL. In Figures 2 through 5, the image sequence runs in a counter-clockwise circle, starting with the upper left corner. All target assemblies include fiducial wires to be used for resolution, focus, and position calibrations. Pre-event static images are always

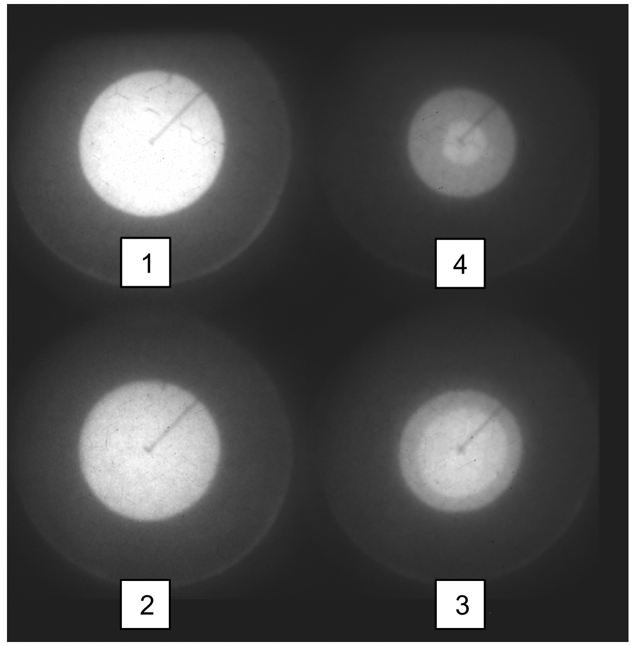

Figure 2. HF-2, raw images taken on January 11, 2002.

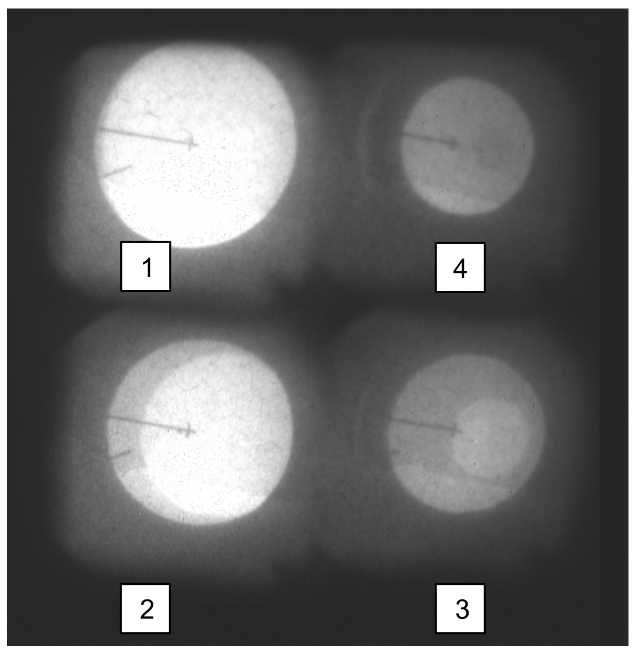

Figure 3. HF-3, raw images taken on January 24, 2002.

taken and compared to the event images. This allows exact velocity and shape to be measured.

Images of Hydro-Features (HF) -2 and -4 (shown in Figures 2 and 4) provide data on shock convergence near the axis in the symmetric target. The Figure 4 images have been dewarped through computer processing to remove distortion of the optical and camera systems. Figure 3 shows images from the HF-3 off-axis convergence experiment. The HF image inner shadows infer shockwave positions and the outer shadows are material interface positions within the target.

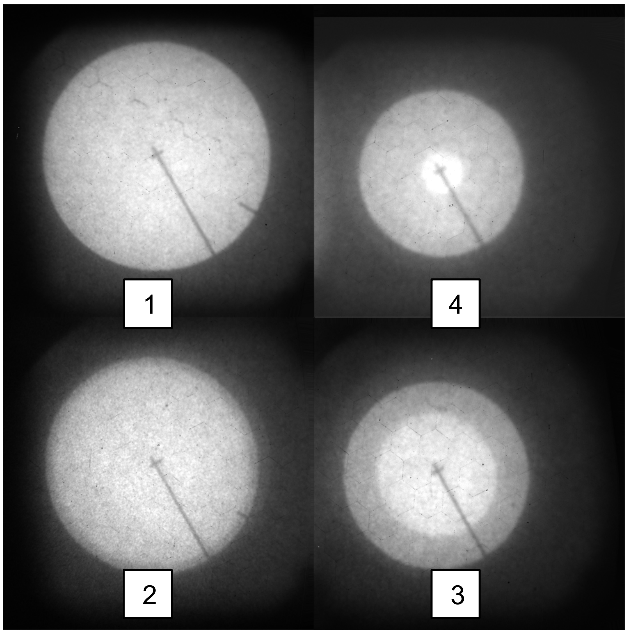

Figure 4. HF-4, dewarped images taken on February 11, 2002.

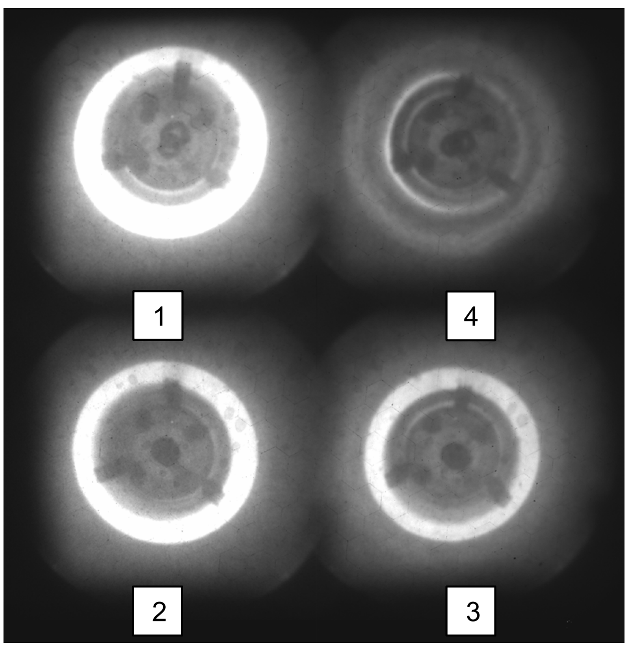

Figure 5. Spall 2, raw images taken on April 3, 2002.

The Spall 2 images (shown in Figure 5) are among other examples of dynamic axial x-ray images taken at Atlas in Los Alamos. They are used to study material failure at a surface during shock. Surface velocity diagnostics are located in the center of the target.

IV. SUMMARY

We have designed, assembled, and operated an axial x-ray imaging system at the Atlas pulsed power facility in Los Alamos. This diagnostic takes four sequential x-ray snapshots of the material density moving through the target region during dynamic experiments looking along the center machine axis. These images are used, in coordination with other diagnostics, to improve physics models of shocked materials.

V. REFERENCES

[1] H. A. Davis, E. O. Ballard, J. M. Elizondo, R. F. Gribble, K. E. Nielsen, J. V. Parker, and W. M. Parsons, "The Atlas Power-Flow System–A Status Report," IEEE Transactions on Plasma Science, vol. **28**, (no. 5), pp. 1405–1413, (October 2000).

[2] D. Platts, M. P. Hockaday, D. Beck, W. Coulter, and R. C. Smith, "Compact Flash X-ray Units," 10th IEEE International Pulsed Power Conference, pp. 892–895, 1995.

[3] R. T. Olson, D. M. Oro, B. G. Anderson, J. K. Studebaker, K. R. Alvey, K. R. Peterson, and B. C. Frogget, "Radiographic results from the NTLX series of hydrodynamic experiments," 13th IEEE International Pulsed Power Conference, pp. 362–375, June 20, 2001.

[4] M. C. Myers, J. R. Boller, R. J. Commisso, G. Cooperstein, D. D. Hinshelwood, S. B. Swanekamp, and F. C. Young, "Characterization of LANL A1-Series Marx Flash Radiography Source," IEEE International Pulsed Power Conference, pp. 1086–1089, June 1999.

[5] J. K. Studebaker, "Atlas X-ray Hazard Control Plan for Use with the P-22 Flash X-ray System," Los Alamos National Laboratory, P-22-2001-008, August 2001.

[6] "Physical Properties of Common Inorganic Scintillators," on the Website of Saint-Gobain Crystals and Detectors at http://www.detectors.saint-gobain.com/ [cited May 5, 2005].

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